

REVIEW - BACTERIAL CELLULOSE: AN ECOFRIENDLY BIOTEXTILE

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ABSTRACT

The bacterial cellulose (BC) has aroused great industrial interest due to its attractive properties if compared with vegetable cellulose. The BC is a biomaterial produced by natural processes, is degradable and promotes low toxicity to the environment; additionally, it is able to play the role of a textile surface. For the development of this type of material for the textile industry, biotechnology has been conducting research in the area of biotextiles and biocomposites aimed to combine the study of textiles and biological experiments to obtain products with technological applications. Accordingly, this review discusses the knowledge obtained about BC over the years, especially in the textile area, with a focus on the advancement of research in order to enable the production of BC on large scale.

KEYWORDS : Bacterial Cellulose, Fermentation, Biotextile, Ecofriendly, Sustainability

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INTRODUCTION

The choice for textile solutions is justified to the extent that concerns to sustainability, with its parameters of social, environmental, cultural and economic, and is shared in various forums. Recent studies (Elena, 2014) identify the unsustainability of the textile industry due to the large consumption of natural resources and inputs to meet the high demand for manufactured garments. The fashion industry, responsible for a good part of the emissions of greenhouse gases, and the consumer culture that involves, needs to rethink its productive chain, starting with the raw materials used in the manufacture of its products (Clementino, 2016).

The volume of textiles produced and discarded worldwide is quite significant, especially when linked to the development of fashion products, clothing or accessories and footwear, all characterised by a short life cycle. It is obvious that the planet does not support a significant increase in the production of yarns and natural filaments, even from animal, vegetable or mineral origin, due to restrictions related to the need for expansion of areas dedicated to food production. Additionally, the need for production of yarns and synthetic filament to dress the world population which have greater time to degradation and intense use of non-renewable natural resources (Thiyagarajan and Hari, 2014; Kaur and Chanchal (a), 2016). On the other hand, there are concerns not only with

the production of fiber and filaments, but with all the processes that pervade the textile processing, including finishing tied to fashion trends. In this sense, water consumption, effluent treatment and energy demand, is the focus of research to minimise the harmful effects to the sustainability (Jain and Gupta, 2016).

The fabrics that are used in making clothes and accessories have remained the same for thousands of years by the use of the interlacing process with warp and weft or by the formation of laminated and malleable surfaces using mechanical, chemical or thermal processes, including the non-woven fabrics (TNT) (ABINT, 2016).

In addition to the textile, other coverings surfaces are used in design steps of product development as clothes, accessories and shoes. Animal leather is a structure formed by the disordered arrangement of fibers of various species of large, medium or small animals. Once tanned, the leather goes through processing steps aimed to improving the aesthetic and sensorial aspects to the final product (Brasil (a) 2016; ABINT, 2016). However, the use of formaldehyde and derivatives from coal tar processing of skins impact negatively on the implementation of the decision on developing leather products as it raises environmental and social risks (Ortolano, 2014).

On the other hand, the ecological leather can be produced in various ways. The so-called vegetable leather is produced with natural latex extracted in a sustainable way, using technological innovations and removing intermediate processes, minimizing the unhealthy, excessive consumption of water and electricity. Pineapple fabric is a called eco-leather made from pineapple residues (fibres and leaves), having been patented by Carmen Hijosa, Director of Spanish startupPiñatex. Pineapple fibers are traction-resistant, flexible and compatible with dyes and pigments, and are already being used in designed artifacts of great brands of the fashion market (Miwa, 2016; Farbe, 2016). The Muskin, taken from the top of the mushrooms, is named as a vegan leather, and it has a large capacity to absorb moisture and being naturally waterproof.

According to Lacerda et al. (2012), biomimetics will play a key role in the process of industrial revolution, which will focus on how the product is made and their contributions to sustainability. Thinking of a closer relationship between living organisms and products, instead of using the "To Be" as inspiration, the trend is to use it in the manufacturing process or in the product itself. With this, searches using living systems as an ingredient are increasingly being carried out in the United States, where a large part of its research budget has been employed in jobs with genetically modified products (Lasky, 2013; Abreu, 2016).

In the last 50 years, the textile industry has been very present in traditional research and somewhat unusual inventions to wearable artifacts made from fibers, filaments and high quality fabrics and technology (Grbic, 2016). Discoveries of various materials and manufacturing processes have enabled the development of new fabrics and, consequently, a textile revolution. Wearable biotechnology produced by researchers in the areas of design, fashion, biology and engineering feature to the textile market new possibilities of fabrics and surfaces, seeking ecologically correct and sustainable solutions (Elena, 2014).

BIOMATERIALS

The biomaterials are substances or a mixture of natural or artificial substances, that in the manufacturing process encompasses several important steps, since the selection of material, where there is a wide range of options, and can be used metals or metal alloys, ceramics, composites, woven or knitted fabrics and polyester polymers of diverse nature. The biomaterials arise to improve the quality of life of individuals, increase the longevity and comfort, featuring

biocompatibility, i.e. the absence of toxicity, not causing immune or allergic reactions and not showing recalcitrant or teratogenic action (Ripper and Finkielstejn, 2016).

The study of the mechanical, thermal, electrical and surface properties are necessary to biomaterials advances. Textiles used for the production of clothing must provide specific answers to their application as (Oliveira et al., 2010; Monteiro, 2012):

- Bioinertes, not interacting or interacting minimally with the surface touched.
- Bioactive, interacting with the surface played as textiles used as support for medicines.
- Bioabsorbed, incorporating or dissolving the surface touched when the surface that is being treated is replaced.
- Biodegradable, being absorbed into the environment after the disposal.

Sciences such as medicine, nanotechnology and textile and materials engineering have been developing together important advances in the field of biomaterials, with diverse purposes as prosthetics, human skins, support for medicines and geotextiles (Silva et al., 2012; Carretero, 2013). On the other hand, Suzanne Lee (Andreotti, 2015; Tom, 2011) envisages the use of a biomaterial applied to the production of clothing aiming to partially replace the vegetable pulp. The above-mentioned author manufactures clothes with a biotextile produced from a bioculture; however, laboratory tests are necessary to enable the best wearability for pieces made with the biomaterial, which is being presented as a sustainable product, obtained by synergistic action of a microbial consortium (Carvalho, 2016).

The skin is a vital organ that provides protection from infection and dehydration of dermal and epidermal layers and should be kept full to maintain the health of individuals. Broega et al. (2007) considers the clothing a second skin that must protect the body from cold and heat. Thus, the textiles made from polymeric materials are manufactured in industries and present themselves as acceptable raw materials since the most remote times for the production of clothing (Almeida et al., 2013; Broega et al., 2007; Gandhi and Heinrich, 2010; Gautam and Lee, 2016).

Textile Inputs

The growing production of textiles and clothing products stems from the increase in population and is reflected in all sectors, starting with the raw materials. Inside the textile industry it is known that natural fibres are not sufficient to meet present and future demand. Many chemical fibers and filaments are employed to increase the options among the materials and in an attempt to maximize chemical and physical properties of the products offered by the textile companies. Fibers and membranes developed by biotechnological processes are also being presented as sustainable alternatives for the production of clothing and many designers are thinking on biotechnology as a creative tool (Berlim, 2012).

Renewable raw materials are the basis for the 'green' economy. The search for products and industrial processes that reduce carbon dioxide emissions and waste, as the recycled materials and biotechnology, is critical to minimize the environmental impacts in the 21st century. Sustainable clothing designs are structured for all phases of the life cycle, from production to disposal (Kaur and Chanchal (b), 2016; Elena, 2014; Alison, 2014).

Natural fibers are, par excellence, renewable resources, 100% biodegradable and an elegant choice for users. Currently, the fashion 'eco-driven' or 'sustainable clothing' presents itself as a global concern for producers and consumers. The natural textile fibres originate from animal or vegetable sources are more expensive due to the slow manufacture process when compared to chemical fibres (Elena, 2014; Jenny, 2009).

Silk is an extracellular fiber produced mainly by a caterpillar of certain types of moths. It is the only textile raw material that nature produces already shaped as a filament. The most noble and expensive silk comes from an insect, *Bombyxmori*, known as silkworm. Through the sericiglands, the insect secretes a protein, sericin and fibroin rich, with a length of up to 2000 m, which will form the cocoon. Silk offers features like brightness, smoothness and luminosity, combined with excellent tensile strength and elasticity, plus very low allergenic potential (Gao et al., 2016; Winifred, 2007; Diná, 2007; Doris, 2007; Jenny, 2009).

The lamb fur is called wool. Wool is made up of albumin and grows from the epidermis of the animal, being removed by shearing. It is a fiber more or less short, thin and wavy, and presents excellent properties such as thermal retention, absorbency, recovery rate of moisture, elasticity and stretching, warm touch and a variety of colors between shades of white, yellowish, brown, grey and black, among others (Luiz, 1984; Nunes, 1999; Erhardt et al., 1975).

Many fibrous vegetables produce fibers that can be spinning and weaving for the production of various types of textile materials. Vegetable fibres can be removed from the leaf, fruit, seed and stems of plants. Regardless of the place of retreat, cellulose is the main chemical component in combination with lignin, hemicellulose and pectin. The field of employment of natural fibres is quite broad, covering classical applications in the textile industry, use as reinforcement in thermoplastic and thermosetting polymeric matrices and, more recently, the use of absorbent materials like heavy metals in industrial waste treatment, among other applications (Winifred, 2007; Jenny, 2009; Luiz, 1984; Nunes, 1999; Erhardt et al., 1975).

Cotton is a cellulose fiber commonly used for making clothing. The cotton fibers grow attached in several kinds of genre '*Gossypium*'. It is a flat ribbon of rough surface that contains impurities, a variety of colors, brightness off, hydrophilic, it retains heat, has soft touch, high tensile strength and medium elongation and elasticity potential (Winifred, 2007; Luiz, 1984; Nunes, 1999; Erhardt et al., 1975).

Flax is also a polymer of cellulose extracted from the stem of the flax plant (*Linumusatissimum*). It is the second most important raw material of vegetable fibers for textile industries, and is considered a long, bumpy fiber, resistant, low modulus, hydrophilic, yellowish appearance, silky and cold touch (Luiz, 1984; Nunes, 1999; Erhardt et al., 1975).

The biotêxteis are the result of a plot or a tangle of natural fibres that is presented as a structured and resistant blanket. It can be produced as a polymer matrix biocomposite (textile) and preferably has some support from other natural sources in order to add properties to the new material and reduction of environmental impacts (Wei et al., 2015). The composition, the characteristics of the soil and the climatic and environmental conditions determine the time of degradation, since, these factors change the resistance and durability of biotextile. The biotextile produced with cellulose only has its total decomposition among 3 and 5 months (Tenax, 2016). Therefore, biotextiles are being presented as a great innovation in the textile and fashion area, considering that these biomaterials are produced from the cellulose synthesis by bacterial action, being considered as the fabrics of the future according to bioengineering (Almeida et al. 2013; Elena, 214; Carvalho, 2016).

Bioculture

The bacterial cellulose (BC) offers excellent properties for application in the textile area, considering that it is being used as a raw material for the development of many products and application in various areas of knowledge. This biotextilelooklikes as a gelatinous pulp film formed by interlacing cluttered of microfibrills, when being developed from

the cultivation of microorganisms in an aerobic, aqueous medium and in presence. These micro-organisms, symbiotic association of bacteria and yeasts, forms a kind of fungus on the surface that accumulates between the surface of the liquid and the liquid portion (Tsalagkas et al., 2016; Paximada et al., 2016).

According to Bunch (2011), the membrane of BC, when drought, presents a considerable tensile strength and durability, in addition to natural dyeing accessibility. It is also able to be cutted and assembled as a garment by the tradional processes of patternmaking and sewing, as shown in Figure 1.

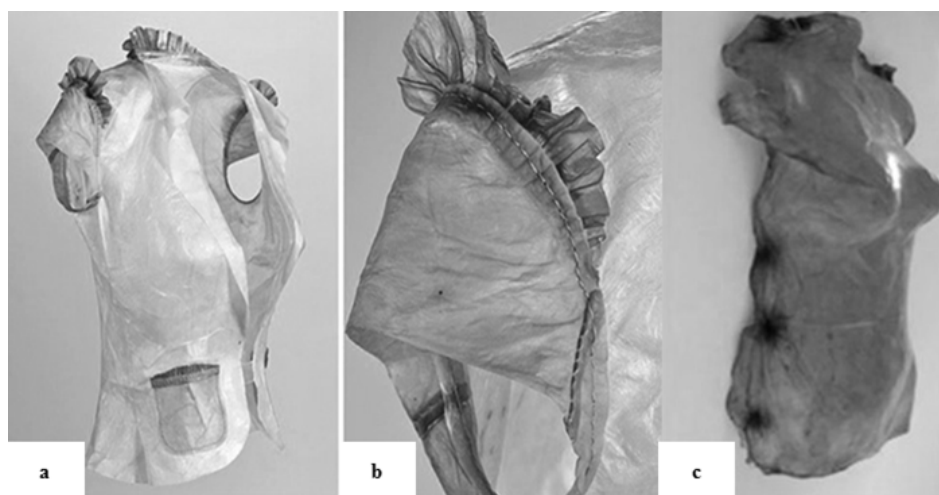


Figure 1: Garment Examples Produced with BC Films.
(A) Clothing Made With Flat And Draping Patternmaking Techniques;
(B) Vest Sleeve Detail Using The Straight Stitch and Darts (C)
The Front Base of A Garment Using Draping Technique

Biocultures are textile membranes selfproduced and are grown from bacteria that bind active enzymes with cellulose fibres in a material of similar characteristics to a non-woven fabric (NW) from cellulose synthesis of sugar during the period of approximately two weeks. Hence, this fibrous membrane is extracted and dried, depriving the microorganisms of their nutrients, making them inactive immediately (Carvaho, 2016; Abitbol et al., 2011; Cacho, 2011). According to Lee (2016), after obtaining the pulp, the thick gelatinous layer is dry, sometimes dyed and then used as fabric for the production of clothes.

The addition of a symbiotic culture of yeast, Kombucha and other microorganisms to black tea or green tea sweetened, transforms this mixture in a culture medium rich in natural nutrients able to assist the growth of bacterial cellulose, glucuronic acid, gluconic acid, lactic acid, vitamins, amino acids, and many other antibiotic substances (Carvalho, 2016).

The bioculture field studies complex natural processes using consortium of yeasts and bacteria in the development of textile surfaces, presenting itself as a reference in studies of Suzanne Lee, Director of 'The BioCouture Research Project', which is working with scientists to unite design with bio and nanotechnology to attempt in developing sustainable garments using green tea, sugar and some micro-organisms. The 'BioCouture project' was included on Time Magazine as a 'Top 50 best inventions of 2010' (Andreotti, 2015; Tom, 2011). Today, the 'BioCouture' is a design consultancy pioneered of biomaterials for the areas of fashion and sportswear, with headquarters in London (Lee, 2016).

The presentation of the fibers of BC, analyzed in a microscope, makes it possible to identify a tangle and fibers in the composition of biomaterial, which has similar features of the definition of the Institute of Metrology (IMETRO); However, the BC membrane can be considered a nonwoven fabric of biological origin, such as define Brazil (b) (2016): 'nonwoven fabric is made from fibres that are crowded and set uncertainty, not through the most common textile processes, which are spinning and weaving'.

According to Andreotti (2015), Suzanne Lee reports BC film as a biomaterial that 'is not only biodegradable but compostable too; so you can throw it away as you would with your vegetable peels'.

The bioculture offers self-destruct, self-fixed and remodeling properties when it comes in contact with liquids. To prevent the self-destruction of the material, it is intended to add water-repellent molecules. The ability to remodel allows the material to be fastened to a support, enabling the production of garments carried on a mannequin or in a predefined shape dummy, assuming the desired seamless modelling and featuring textures and color depending on the specific medium. Another technique would be the immersion of the dummy in the middle of cultivation of microorganisms (Andreotti, 2015, Abitbol et al., 2011).

The BC was presented at the Wearable Futures Conference 2014 as a material for the areas of design and technology. On the occasion of the Conference, Suzanne Lee presented jackets, skirts and shoes made from biomaterials (Figure 2). These biotextiles were produced by bacteria in a tank containing a liquid culture medium for the formation of cellulose film with similar properties to leather (Monks, 2014).



Figure 2: Garments Presented by Suzanne Lee on Wearable Futures Conference 2014

CELLULOSE

Cellulose is one of the most abundant natural polymers on Earth. Most of these polymers are produced by plants, being so called vegetable cellulose (VC) (Garcia et al., 2013). The increasing demand of vegetable cellulose derivatives (VC) in the world increased the consumption of wood as a raw material, causing deforestation and environmental problems at the global level (Park et al., 2012). Although the plants are the largest sources of cellulose, several types of bacteria are capable of producing cellulose as an alternative source.

The bacterial cellulose (BC) was initially reported by Brown in 1988, which identified the unramified film growth with the chemically structure equivalent to the cellulose of plants (Esa et al., 2014).

Classified as a carbohydrate, cellulose ($C_6H_{10}O_5$)_n is a polymer that contains carbon, hydrogen and oxygen, being composed of linear chains of not branched molecules β -D-glucose linked by β -type 1.4 glycosidic linkages that interacts each other via intramolecular and intermolecular hydrogen bonds (Figure 3). The polymeric structure starts its formation

when two glucose molecules join together and form the cellobiose, considered the structural unit of repetition of the cellulose molecule. The microfibrils cellulose, which are long and rigid molecules, are formed by hydrogen bonds, responsible for the rigidity of the chain and the formation of straight and stable fibers that elevate the mechanical resistance and make the pulp insoluble in water and most organic solvents (Santos, 2015; Ul-Islam et al., 2012; Brown et al., 1996).

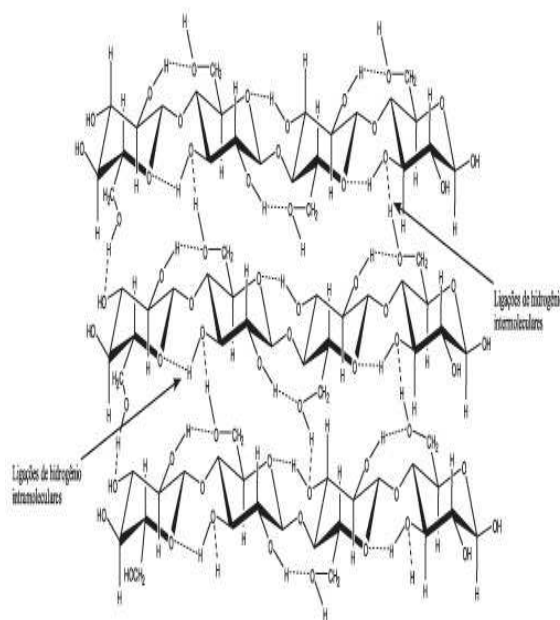


Figure 3: Chemical Structure of Chain β (1 \rightarrow 4)-Glucan (cellulose) and the Intramolecular and Intermolecular Hydrogen Bonds of Cellulose

The cellulosic microfibril is a natural composite presents in the cell wall of plants and vegetables. It results from the intimate association of four elementary fibrils grouped by a monolayer of hemicellulose, later being surrounded in an array of hemicellulose and lignin (associated with each other through physical interactions and covalent bonds). The resulting structure of this chemical arrangement is called elementary fibril, which has features of insolubility in water and high degree of crystallinity (Antonio et al., 2012).

Some genera of bacteria as *Gluconacetobacter*, *Rhizobium*, *Sarcina*, *Agrobacterium* and *Alcaligenes* produce a linear polymer cellulose strongly associated through hydrogen bonds that are responsible for the formation of cellulose fibers with the same chemical structure of VC and relevant physical and mechanical properties for the production of biomaterials (Donini et al., 2010). Acetic bacteria belonging to the family *Acetobacteraceae* (VI) of the genus *Acetobacter* produce bacterial cellulose (BC) especially when mannitol, ethanol, n-butanol, glycerol and lactate are used as carbon sources for cell growth, considering that they do not hydrolyze the starch or lactose and are chemoorganotrophic (De Ley et al. 1984, Holt et al., 1994, Ashtavinayak and Elizabeth, 2016).

The VC differs mainly from its biological even due to its micrometric fibers character, while the BC presents a nano-sized fibers character and are extruded through the cell wall of the bacterium (Donini et al., 2010). Visually, the difference between VC and BC refers both to the appearance as well as the water content. The VC has a fibrous aspect, while BC resembles a gel (Figure 4). However, the functional groups that characterise the BC are the same as those of the VC.

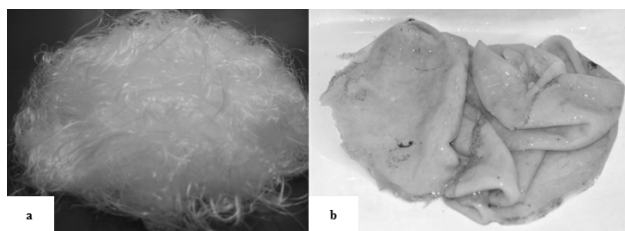


Figure 4: (a) VC has a Fibrous Aspect and (b) BC Resembles a Gel

Bacterial Cellulose (BC)

The BC is the result of extrusion of the material by aerobic bacteria and presents as nanofibers (10-50 nm) also called biocelulose, whose fibers are uniaxially oriented. Microbands with a width of 1 to 9 nm feature a unique nano-structure, have a high degree of polymerization, between 2,000 to 6,000 and offer mechanical properties indicated the development of biomaterials and as reinforcement for biocomposite when compared with other materials (Table 1).

Table 1: Mechanical Properties of BC Compared to Other Materials

Material	Young Modulus (GPa)	Tensile Strength (MPa)	Deformation (%)
Bacterial cellulose (BC)	15 - 35	200 - 300	1,5 - 2,0
Polypropylene (PP)	1 - 1,5	30 - 40	100 - 600
Poly (ethylene tetraltalato) (PET)	3 - 4	50 - 70	50 - 300
cellophane-	2 -3	20 - 100	15 - 40

Source - KLEMM et al.(2006) in Santos (2010)

The BC microfibrills were first described by Muhlethaler, in 1949, being about 100 times smaller than those of VC (Chawla et al., 2009; Gayathry and Gopalaswamy, 2014). The fibrous network of BC is made from three dimensional tidy nanofibers that result in the formation of a hydrogel sheet with high surface area and porosity (Esa et al., 2014).

A BC, with three-dimensional structure and special properties is obtained when the fermentation process is submerged static (Chawla et al., 2009), producing a high crystallinity biomaterial (60-90%) when compared with the VC (~ 40%) and especially with the cotton fiber (~ 70%) (Pigossi et al., 2015; Barud, 2007; Ross et al., 1991; Brown et al., 1996).

The inter-and intra-molecular hydrogen bonds keep the cellulose chains together, giving also the BC fibers a low solubility and high water retention, as well as high purity, mechanical resistance, elasticity, flexibility, biodegradability, biocompatibility, absence of toxicity, in addition to not be allergic. The BC membranes are elastic, flexible and sterilizable. The BC is being researched in the scientific world as a potential promise for use in various areas of knowledge (Pecoraro et al., 2008; Wang and Du, 2011; Klemm et al., 2006; Donini et al., 2010).

Brown, in 1886, noted that during the process of vinegar fermentation, the bacterium *Gluconacetobacterxilinus*, formerly *Acetobacterxylinum*, and currently called *Gluconacetobacterhansenii*, is able to synthesize BC in the presence of glucose and oxygen (Rangaswamy et. al., 2015; Donini et al., 2010; Klemm, 2001; Hestrin and Schramm, 1954), forming a gelatinous blanket, which was first observed on the surface of vinegar fermentation. After microscopic analysis, the presence of this bacterium was detected in manta. BC production by bacteria of the genus *Gluconacetobacter* was studied in order to evaluate what happened inside the biosynthesis of this biopolymer and extrapolate the process to industrial plants. These bacteria are gram-negative bacteria and are presented in the form of a bat, with high tolerance to acidic

substances, grow in pH values lower than 5.0, are pathogenic and not require of, in particular, a continuous supply of oxygen and carbon for the efficient production of extracellular BC (Esa et al., 2014; Klemm et al., 2001; Barud et al., 2010; Pecoraro et al., 2008; Iguchi et al., 2000). This genus produces a BC that presents unique properties, including high mechanical resistance to traction, possibility of material inserts for composites, high water retention capacity, high crystallinity and a cutting-edge network structure and highly pure fiber. These properties allow many applications in the biomedical and biosensors area, as well as in the area of food, textile and other industries (Hungund and Gupta, 2010).

For the bacteria, the BC works like a flotation mechanism, allowing the organism to remain on a liquid/air interface to obtain oxygen more easily to their growth. It acts as a physical barrier that protects the bacteria from ultraviolet radiation and increases the ability to colonise substrates and its hygroscopic character allowing the retention of moisture and preventing dehydration of the substrate (Donini et al., 2010).

The production of bacterial cellulose (BC) by *G. xylinus* can be obtained in the laboratory using crops on solid and liquid media (Sani and Dalman 2010; Moosavi-Nasab and Yousefi; 2011). The crops cultivation in static cultures, in choppy cultures and in orbital shaker or bioreactor are methods used in laboratory for the production of BC. Different forms of cellulose are produced under these conditions.

In static conditions it is necessary to adjust the aeration of the medium and the concentration of the carbon source in order that a three-dimensional interconnected reticularmente film, similar to a white leather, is produced and emerges to the air-liquid interface when the incomplete oxidation of various sugars and alcohols of the culture medium takes place (Wu et al., 2014; Klemm, 2006). The increase in growth will increase the formation of BC along with hydrogen and C-H bonds (Sheykhnazaria et al., 2011). The synthesis of BC reaches its limit when the film growth toward the inside of the medium imprisons all bacteria, which become inactive due to insufficient oxygen supply (Borzani and Shankar, 1995).

When the experiment happens while stirring or churning condition, irregular pulp particles are produced, similar to spheres (Tanskul et al., 2013). The semi-continuous process in static condition is recommended on an industrial scale, as it can increase the productivity of BC regarding the ongoing process (Esa et al. 2014). Although the BC produced under agitation has low mechanical strength, in the form of pellet or as a tangle of fibers, this method aims to increase the production of BC for industrial purposes (Donini et al., 2010).

Currently, *G. xylinus* is taken as a microorganism model in biosynthesis, crystallization and getting structural properties of BC. More than 100 existing pores in the membrane of that microorganism provides the extrusion of cellulose to form a fibril elementary which has a diameter of 3.5 nm. Approximately of 46 adjacent fibrils join through hydrogen bonds to form a tape that has a width ranging from 40 to 60 nm. The tapes roll up to form the fiber, which are entangled with the other scattered in the culture medium. Intertwined fibres form a gelatinous film called *Zooglea*, which contains about 98% (w/w) of water and features on the surface of the liquid culture medium. Its thickness depends on the time of culture and, usually, can reach 1 or 2 cm (Pecoraro et al., 2008).

The structural characteristics of the BC are directly related to two factors: the strain origin, which determines the reason $I\alpha/I\beta$, consisting of two different crystalline structures, a monoclinic- $I\beta$, cellulose and other triclinic-cellulose $I\alpha$ (Lima et al., 2015) and the composition of the culture medium, which influences the size of the chain. These characteristics also determine the degree of crystallinity and consequently the physico-chemical properties of the BC.

BC production by *G. xylinushansenii* using 2% glucose (as carbon source), with a pH between 5.0 and 7.0 and temperature between 25° C to 37° C as growing conditions, were considered great for static cultivation, since after 2 hours of cultivation was observed the production of a viscous gel in liquid/air interface (Hestrin and Schramm, 1954). For the said bacteria, carbon sources such as fructose, sucrose, glycerol, mannitol, lactose, maltose, sorbitol and cultivation on orbital shaker have been thoroughly tested for the production of BC without success for the formation of the membrane.

The gauge and porous membrane structure produced by BC is a material that acts as a physical barrier against bacteria. It can be dehydrated, but, because of the high absorbent capacity, the BC rehydrates when it comes in contact with liquids, with the ability to absorb the same amount of original liquid (Czaja et al., 2007).

Studies on the kinetics of growth of micro-organisms help studies for obtaining BC membrane with the desired thickness, using based on fermentation processes. Noting the possibility of substantial increase in the productivity of the BC, several authors have worked the theme, using different forms of culture in bioreactors and crops, in contrast with the traditional static cultivation, apart from variations in terms of supplementation. The best performance reported in the literature was 15.3 g/L in 50 hours of cultivation (Donini et al., 2010).

Industrial Waste used in the Production of BC

The standard medium used for maintenance and production of BC, the Hestrin-Schramm (HS) medium, described in 1954, has high cost and requires many additional features, including glucose supplementation, yeast extract, peptone, etc., for cultivation. Recent research has focused on trying to produce smaller cost BC using different strains of producing bacteria cellulose and alternative sources of carbon and nitrogen.

Residues are becoming interesting raw materials for the industrial environment, due to greater environmental awareness of companies and society. Industrial waste have been used to replace synthetic compounds as a relatively inexpensive alternative to reduce or replace the carbon source so that the cultivation of bacterial cellulose reach large-scale industrial applications (Kiziltas, et al., 2015; Huang et al., 2014; Cavka et al., 2013; Kongruang, 2008).

Many works have been conducted in order to test new carbon sources of low cost for the production of BC. The future potential for BC is far beyond the existing applications, especially for the production of large quantities from low-cost raw materials, and may include special textiles, advanced functional materials and packaging (Cavka et al., 2013). The BC production from agricultural waste and industrial waste, including food waste (Moon et al., 2006), wheat straw (Chen et al., 2010; Chen et al., 2007; Hong and Qiu et al., 2008; Kongruang, 2008), fruits (Kongruang, 2008), glycerol (Kose et al., 2013) and cotton-based textiles residues (Hong and Qiu, 2008) has been demonstrated. The advantage in using agricultural or industrial waste not only provides an inexpensive way to produce BC, but also works as an environmental proposal (Li et al., 2015). In addition, the use of such waste materials not only improves the sustainability of cellulose production by microorganisms, but also reduces the environmental pollution associated with the disposal of industrial waste (Li et al., 2015).

Agro-waste is being used to replace the water and/or compounds that are sources of carbon and nitrogen to minimize cost and add value to production of BC (Andrade et al., 2010). Many substrates are being used as a culture medium for the production of BC, since that allows the fermentation of sugars and plant carbohydrates. Milk, buttermilk, coconut water, agricultural residues such as milk, fruit juices, beer, decomposition, unpasteurised or sterilised wines, green or black teas, sisal, among others, have been cited (Czaja et al., 2007; Klemm et al., 2006; Almeida et al., 2010).

The arrangements of the BC nanofibrils produced on substrates whose composition was studied by agro-industrial waste was reported by Career et al. (2010) and Fatima and Martendal (2016), in experiments performed with extract of grape peel, beer, cheese serum and olive oil with or without addition of supplements (carbon and/or nitrogen). Tyagi and Suresh (2016) and Çakar et al. (2014) used molasses of sugar cane. Wu et al. (2014) tested the effluent of a candy factory. The sisal juice and cashew juice have been used in researches developed by EMBRAPA Tropical – Fortaleza/Ceará, Brazil, for the production of BC as an alternative source of carbon (Andrade et al., 2010). Compounds such as mannitol, food quality sucrose (sugar), sucrose and syrup were tested by Mohammadkazemiet. al. (2015). Gomes et al. (2013) used in the residue of oil production in replacement of water as a medium standard HS. Lipid wastewater from corn processing was used by Huang et al. (2014) as medium. Extract taken from Red Maple wood (*Acer Rubrum*) was tested by Kiziltas et al. (2015). All waste showed success in BC production when incubated in choppy conditions or static, under controlled pH between 4-7, temperature between 26-30° C for at least 7 days.

FINAL CONSIDERATION

BC applications in textile area has not yet reached an industrial scale. The potential future for BC, however, is far beyond the existing applications, especially if the searches are able to develop processes for large-scale production from low-cost raw materials or using agro-industrial waste. In addition to the economic potential of this biotechnology polymer, investment in research and industrial interest in the production of this polymer with high added value will reduce not only the disposal of by-products by the reuse of industrial waste, but also global deforestation caused by obtaining the vegetable pulp.

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